Electron Cloud R&D at Fermilab

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Linear Collider Workshop of the Americas

October 1, 2009

Contributors

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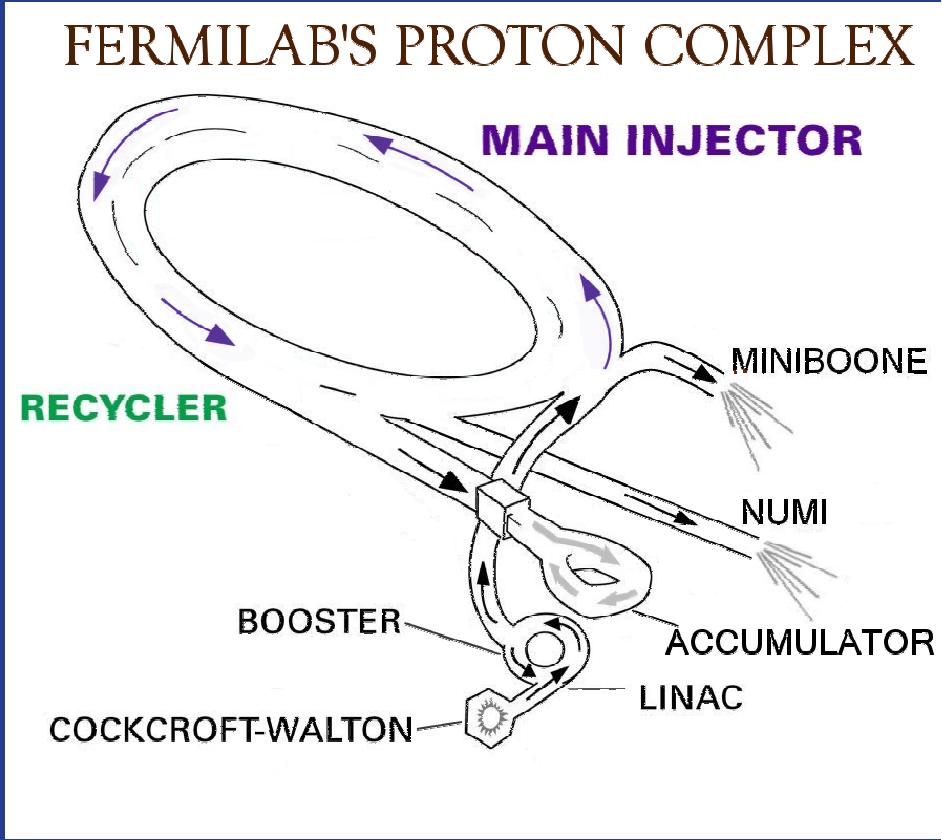
Electron Cloud Working Group: Physicists and engineers working on experiments, instrumentation, and simulation.

Motivation

- Fermilab's ECloud R&D is focused towards proton upgrades of Main Injector
  - NOvA (700kW)
  - Project X (2+ MW)
- Program consists of experimentation and simulation to build Project X
- Additionally, look for general advancement of the question for future machines (e.g. ILC)



Project X

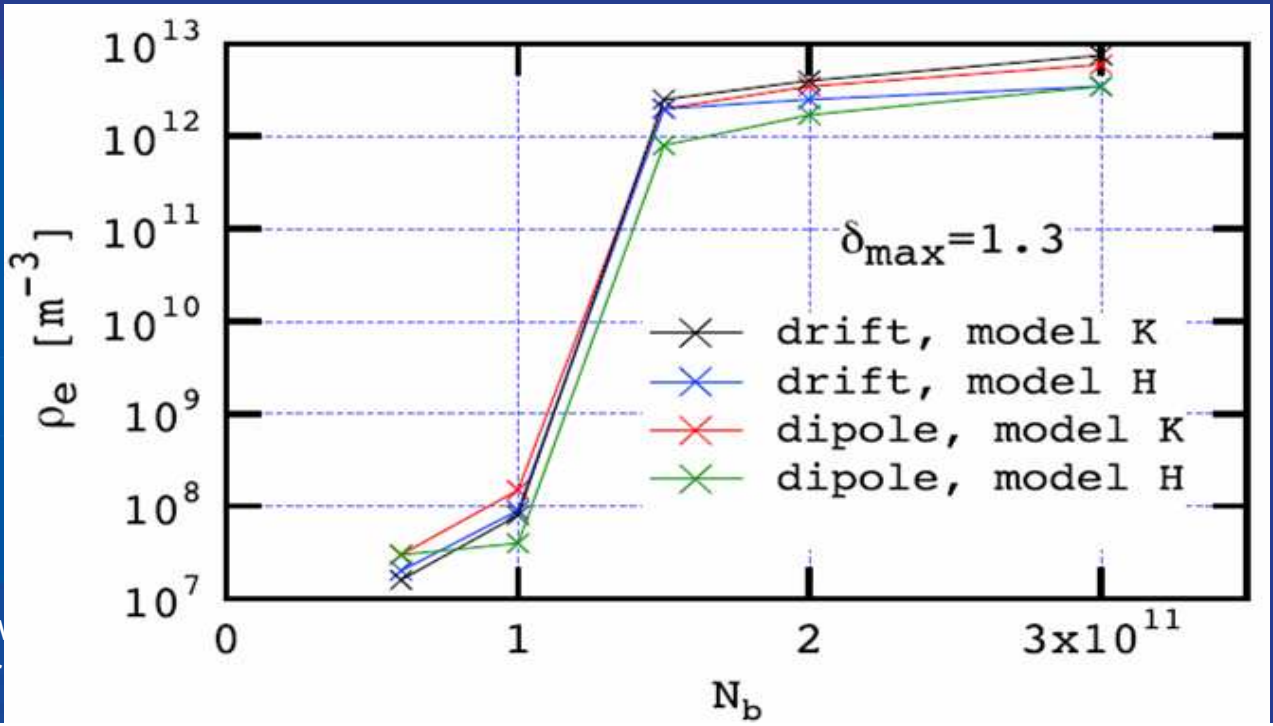
Overview of Activities

- Simulation Input from LBL
- Initial ECloud experimental installation
- Development of instrumentation
  - RFA and microwave
- New ECloud experimental installation
  - Some Preliminary Measurements
- Simulations

LBL Simulation

M. Furman

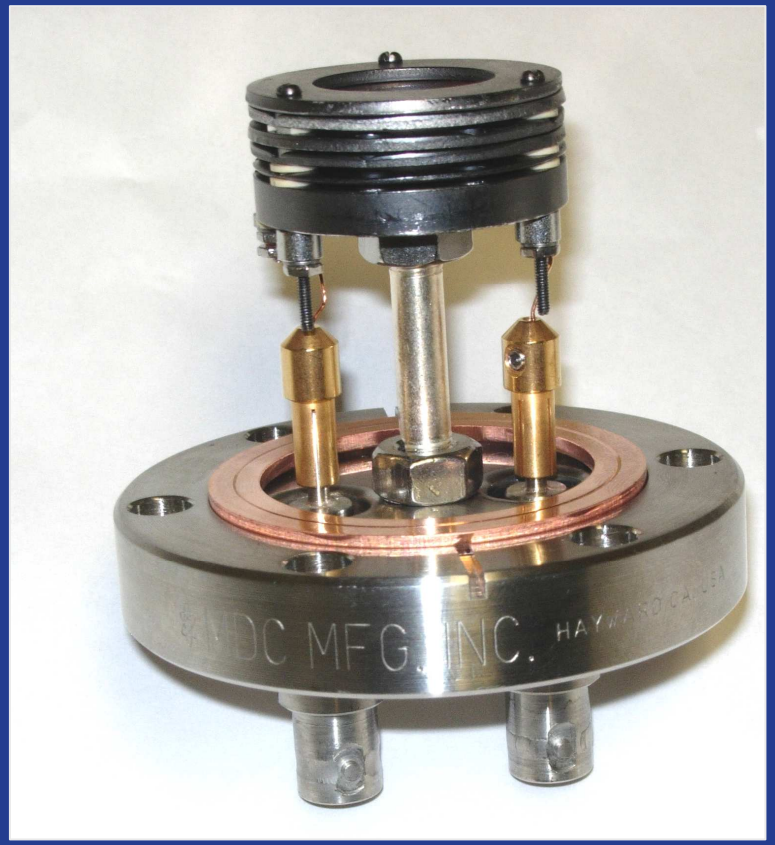
- POSINST simulation suggested that the Main Injector might be near a threshold for electron cloud formation
  - 4-5 orders or magnitude increase of cloud density with a doubling of bunch intensity
- Further simulations have been performed to match measurements
  - Success of comparison has been mixed
  - Progress made in different beam configurations
  - Consistent basic behavior for bunched proton beams:
  - Strong threshold when secondary emission runs away

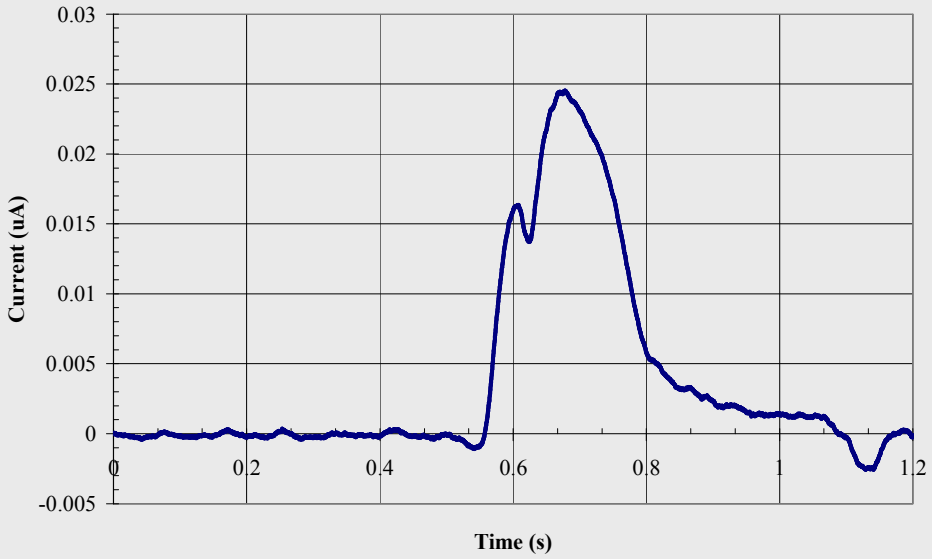


Fermilab

Initial Installation & Measurements

- Argonne RFA (Borrowed)
  - Installed in drift region of MI
- Allowed direct observation of Cloud
  - Time- (energy-) dependent signal
  - Qualitatively

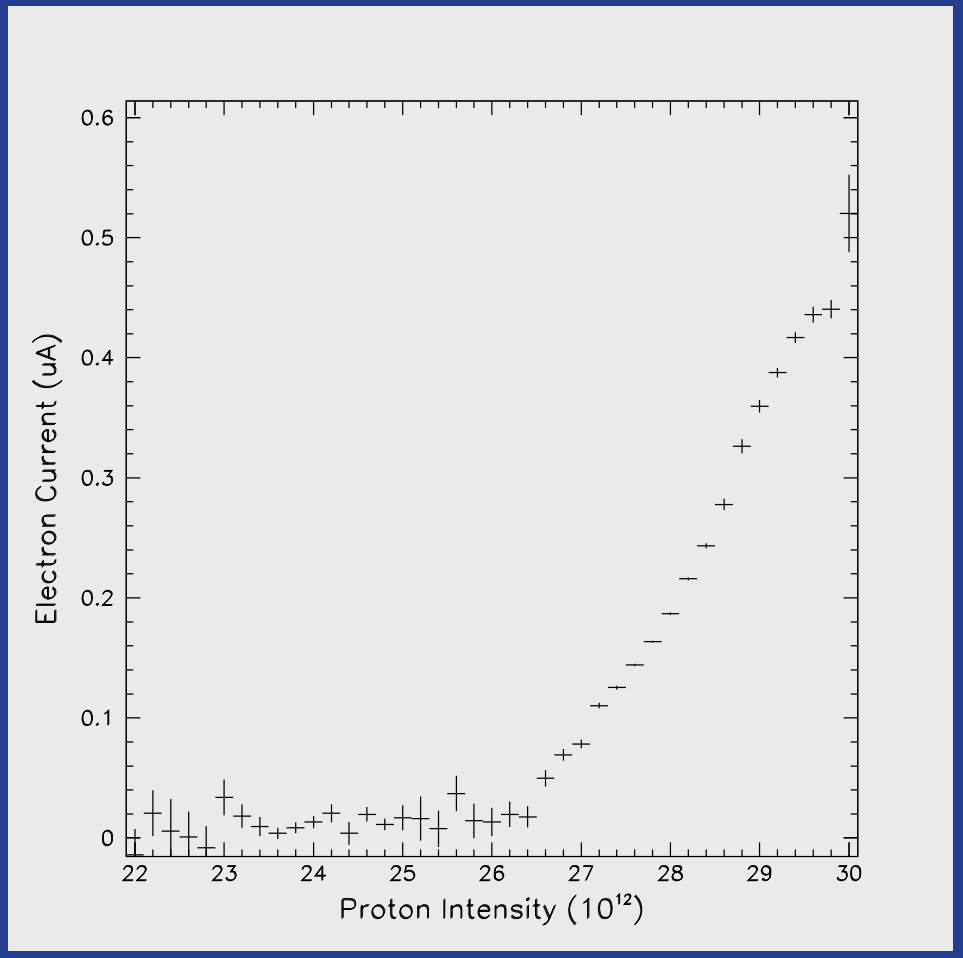




Fermilab

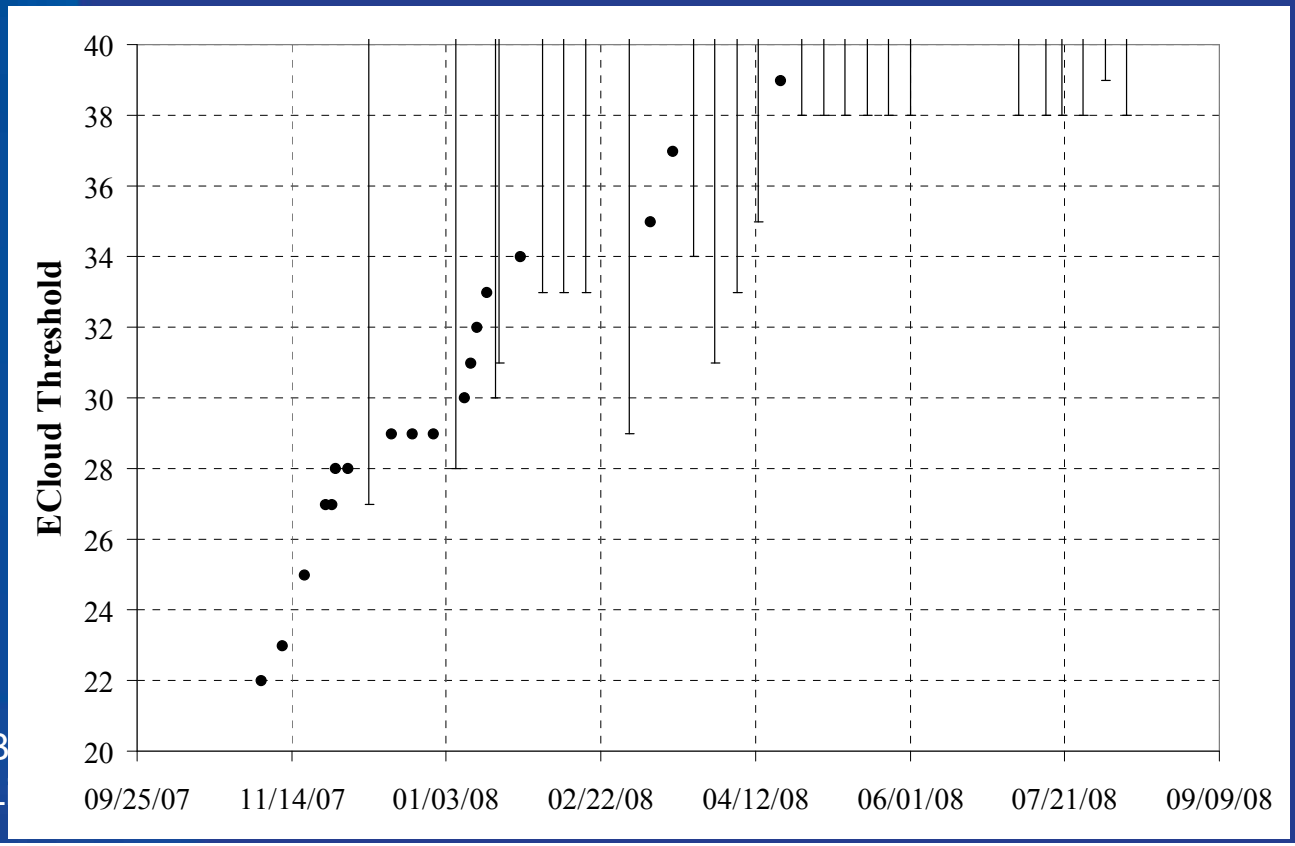
Threshold

- Large number of cycles sampled at maximum current
- Clear turn-on at higher intensities
  - Threshold at ~ 26e12 protons
  - Threshold later moved higher
- Allowed fitting of Furman's simulation to data, giving an SEY



Beam Pipe Surface Conditioning

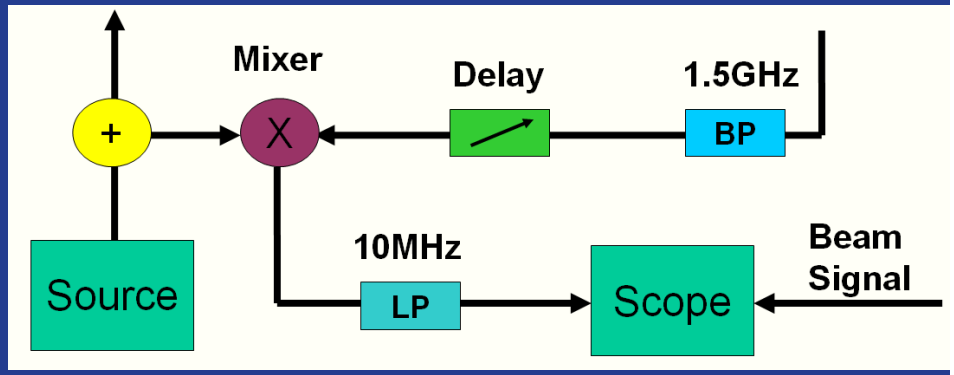
- Threshold evolved with time, moving higher as MI established higher-intensity operation
- When 11 batch became operational, threshold increased quickly (Jan, 2008)
- As beam intensity increased to 40e12, the threshold eventually increased beyond range (March, 2008)
- Conclude that SS conditions well to 40e12 protons, will it to 150e12?

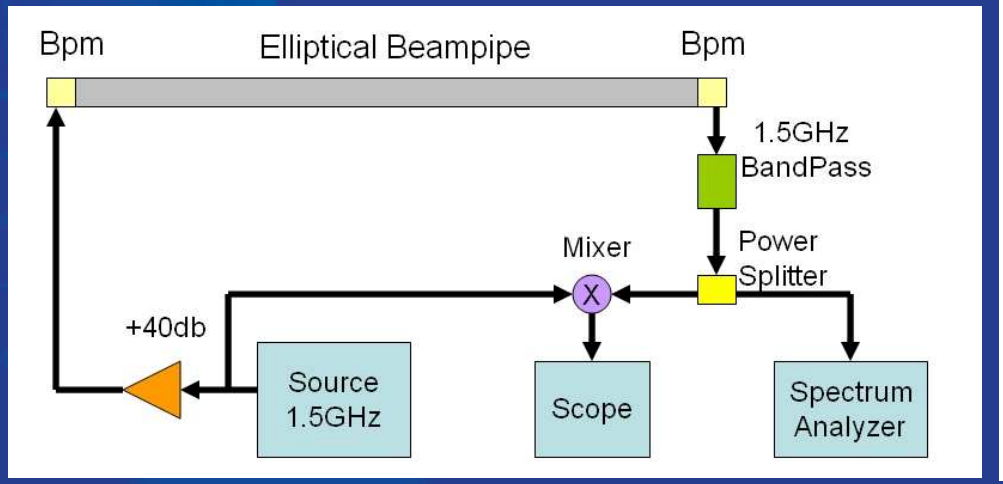


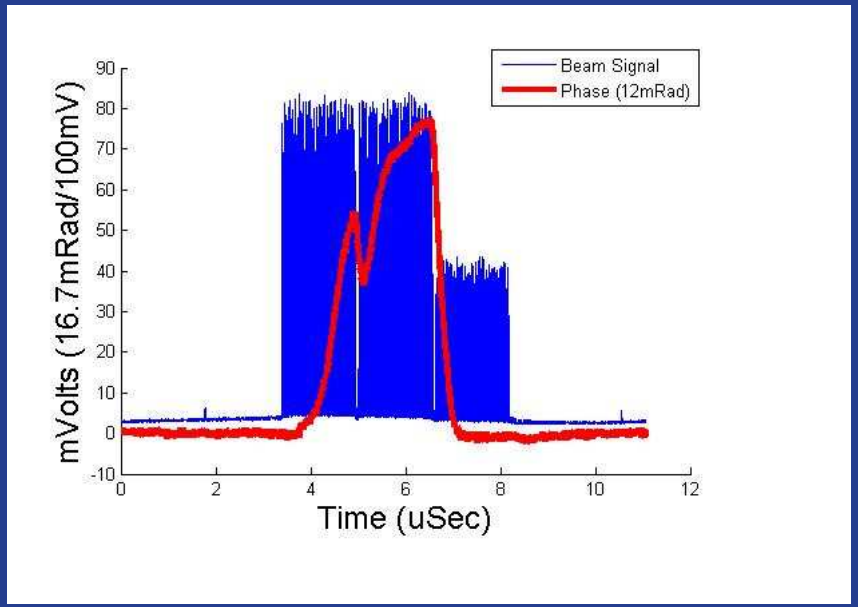
Microwave Measurements

N. Eddy, J. Crisp, M. Wendt

- Sideband and direct phase measurements
  - Very good time-resolution
- Allows measurement in dipole sections
- Will have direct comparison with RFAs
- Need better theoretical understanding of phase shift, particularly in magnets
- See data in Manfred's talk







Project X Plan

- Expect to have to mitigate ECloud
  - < 10% of the machine is open drift space
    - Solenoids don't provide much help
  - Beam Pipes are captured in magnets
    - Grooves and electrodes not practical
  - Will try to optimize beam properties (frequency/distribution)
- Coating is the most straightforward option
  - TiN is well known, also investigate others

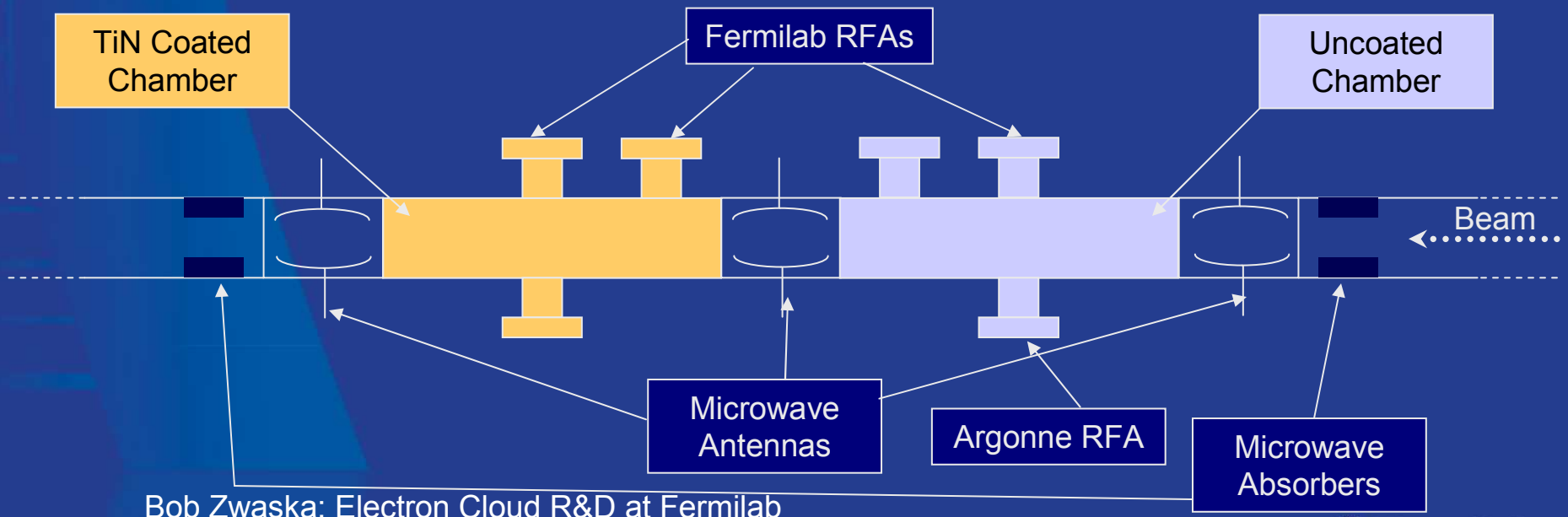
- Project X R&D:
  - Test TiN or other coating in MI
  - Develop process to coat entire MI (and maybe RR)
  - Advance simulations and provide enough experimental cross-checking that we can extrapolate TiN's properties to Project X beam currents

Electron Cloud Experimental Upgrade - 2009

Major upgrade just finished installation, this summer

- 2 New experimental Chambers
  - Identical 1 m SS sections, except that one is coated with TiN
- 4 RFAs (3 Fermilab & 1 Argonne)
- 3 microwave antennas and 2 absorbers
  - Measure ECloud density by phase delay of microwaves

- Primary Goal: validate TiN as a potential solution for Project X
- Secondary Goals:
  - Remeausure threshold and conditioning
  - Further investigate energy-dependence
  - Measure energy spectrum of electrons
  - Test new instrumentation
  - Directly compare RFA and Microwave
  - Measure spatial extinction of ECloud



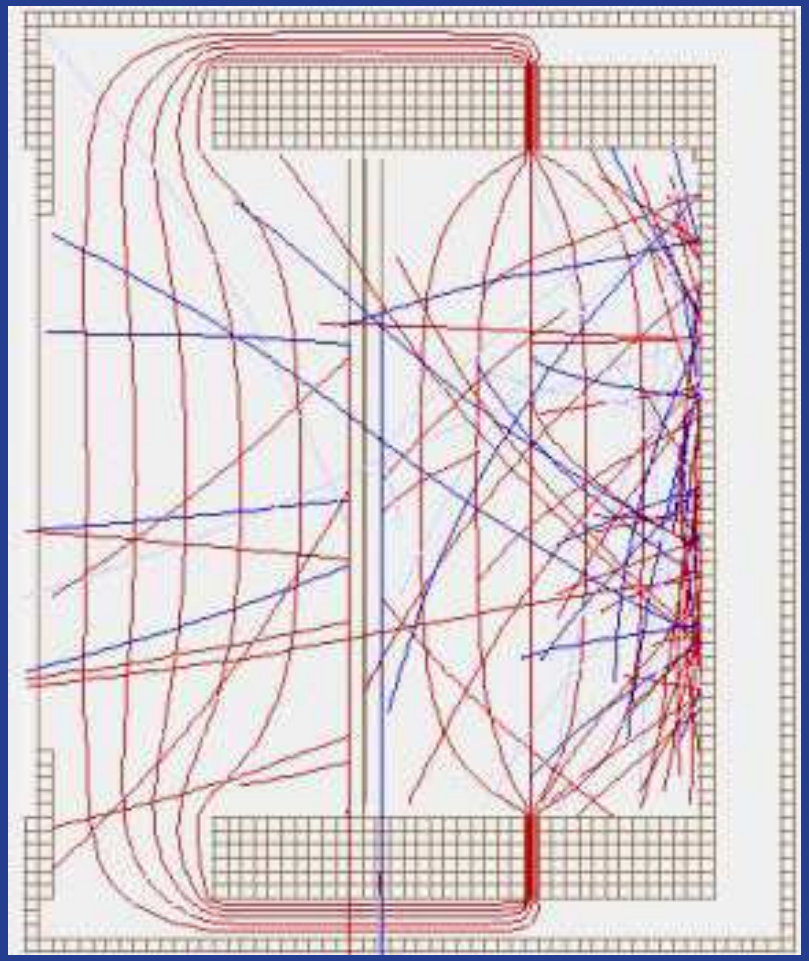
New Detectors

- New RFAs evolved from Argonne style
- Maximize signal with enlarged area and by removing ground grid
  - Ground is provided by the beam pipe
- Shaping of electrodes optimizes energy filter performance
  - Also, more hermetic
- Amplifier/filter in tunnel
  - Better-quality cables to surface

Detector Simulation

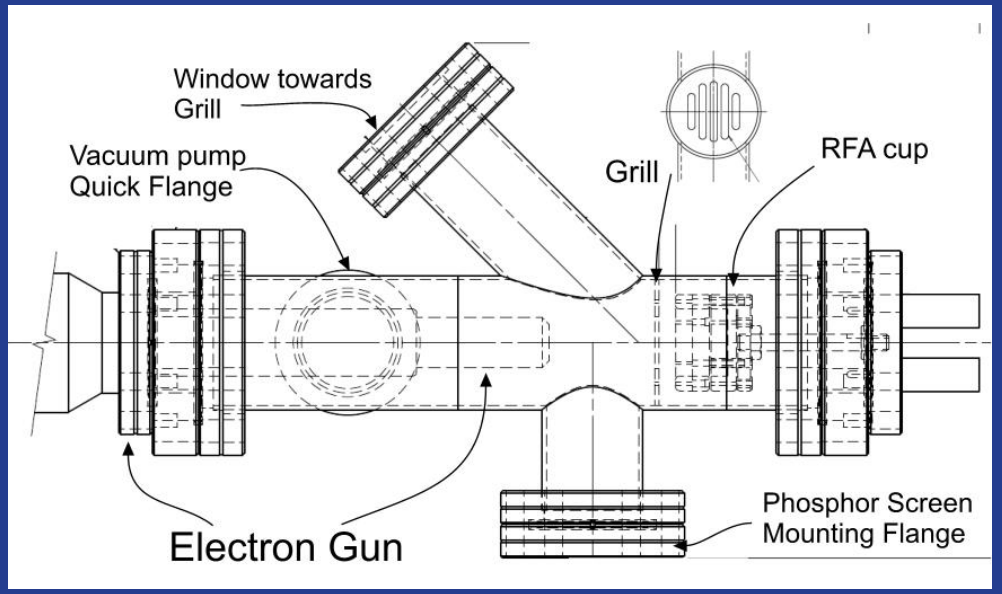
CY Tan, L McCuller

- Electrode layout optimized with SimIon simulation
- Track electrons through a detailed grid
- Summer student added secondary emission functionality
  - Still being validated, but looks promising



Test Stand

- Test new detectors with electron gun
- Demonstrated that the detectors work as expected
- Will allow further exploration of detector effects
  - Secondary emission
  - Magnetic Field
  - Detailed calibration



TiN Coating

Linda Valerio

- Coating of test chambers performed at BNL
- Will need to adapt this procedure for *in situ* coating of 3000 m of Main Injector

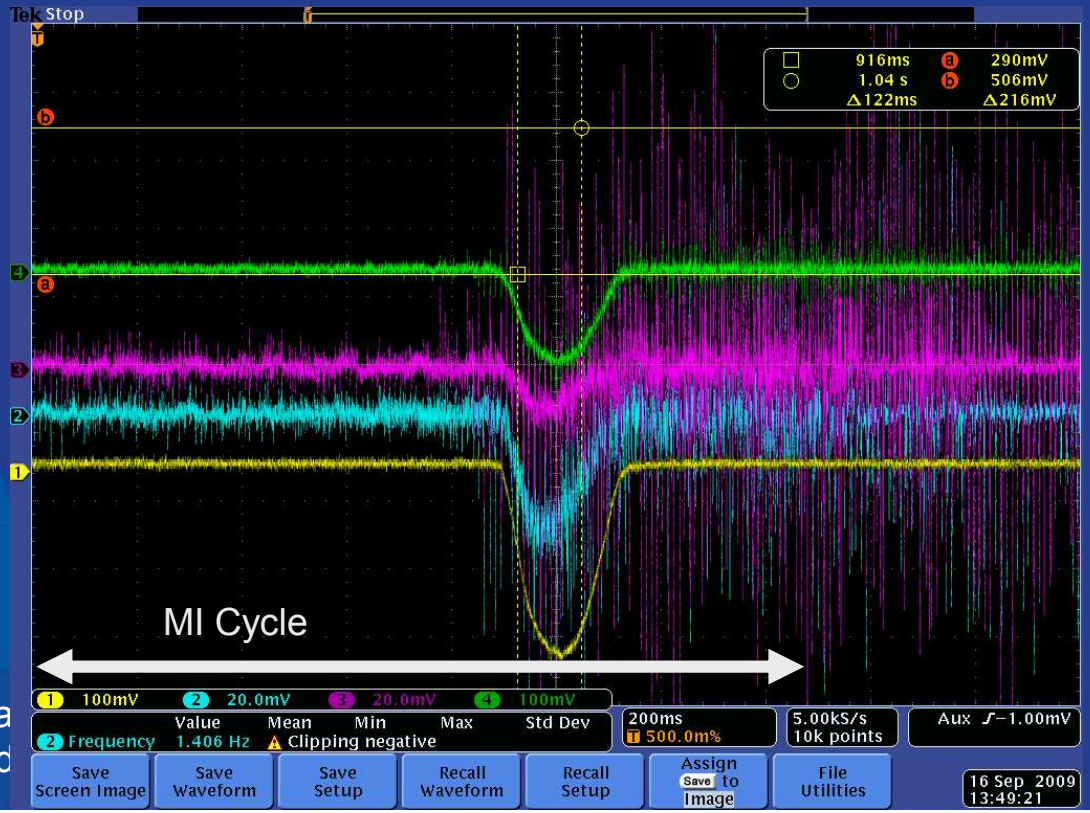
Status of New Installation

- Main Injector beam started 2 weeks ago
  - Intensity has been gradually rising (near maximum now)
- All apparatus have been exercised
  - Starting to understand data
- Initials RFA signals very strong and thresholds low
  - Rapid scrubbing ensued
  - Electron energy scans difficult due to ramping nature
- Microwave data taken, but requires understanding
  - Very short paths (1 m)
  - Cavity behavior? - absorbers were too mitigate
  - May show qualitative agreement with RFAs

Preliminary Data - 9/16/09: 12e12 on 6-batch

- Uncoated (FNAL): 280 nA
- Uncoated (ANL): 110 nA
- Coated (5”): 25 nA
- Coated (mid): 15 nA

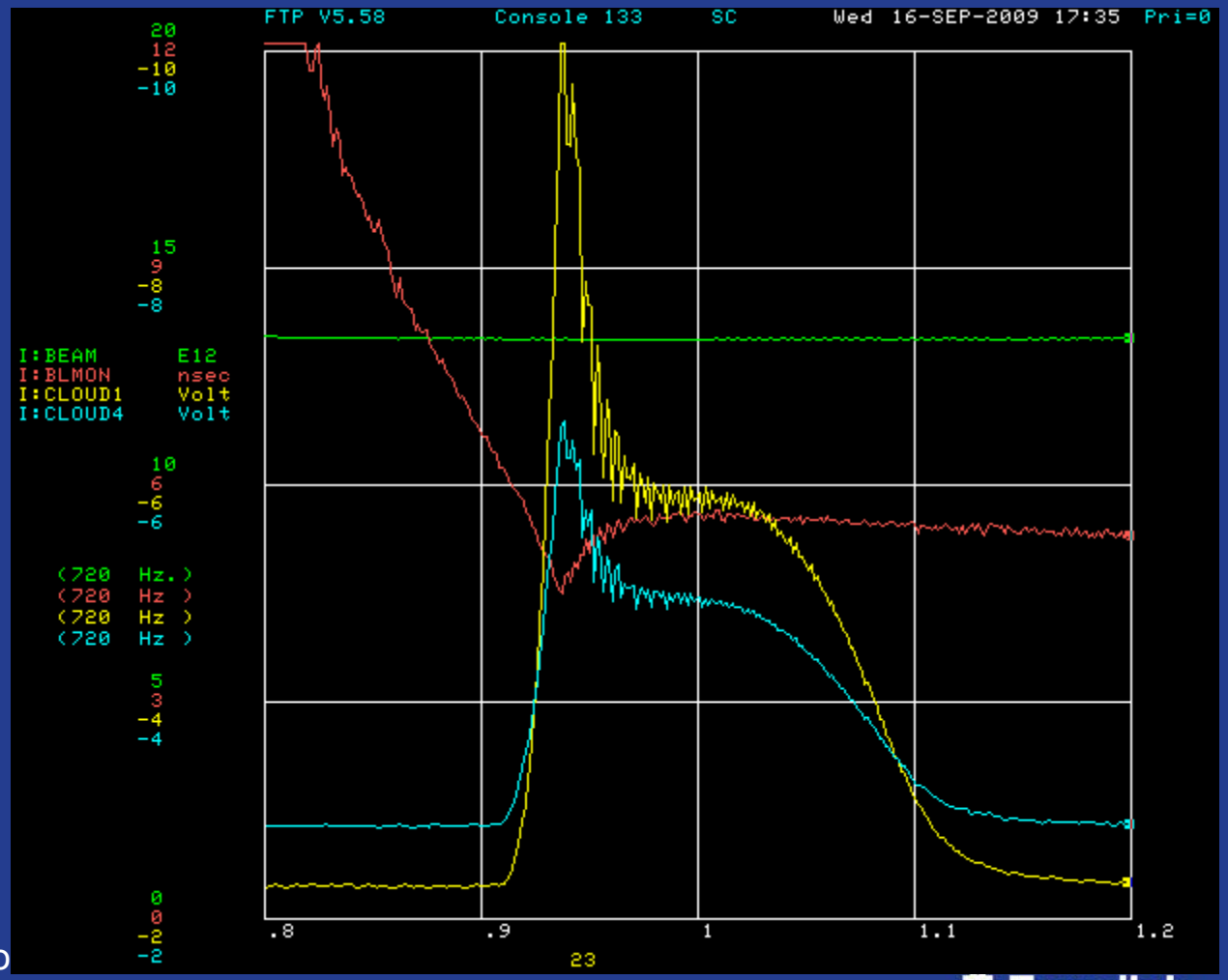
- FNAL/ANL ≈ 2.5
- Uncoated/Coated ≈ 18
- Longitudinal Penetration Distance ≈ 4 cm (e-folding)
- Temporal structures are mostly similar, and similar to what was seen before



Fermilab

Preliminary Data - 9/16/09: 13e12 on 11-batch

- Biased at 120 V
- Red line shows bunch length



Preliminary Data - 9/18/09: 26e12 on 11-batch

- Time duration is much larger
  - Extends to end of cycle
- Max current: 3.6 uA
- Uncoated/coated is ~ 2 in peak
  - Greater in tails
  - Both in deep saturation at max
  - Differential scrubbing
- BPM shows skew

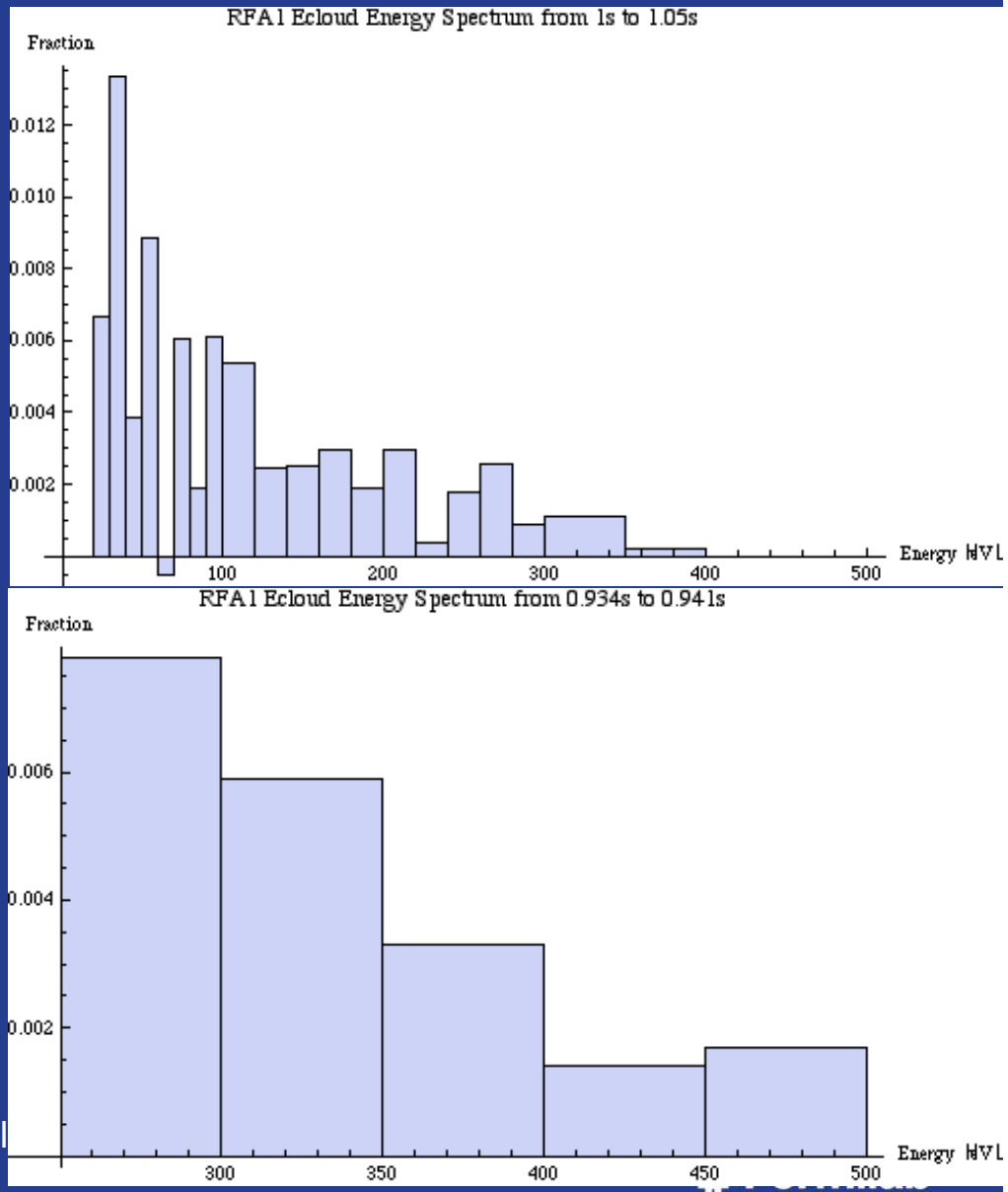
Preliminary Data - Early Conditioning Summary

Rough Thresholds – more precise numbers when data fully analyzed

Date	Uncoated	Coated
9/16	10	13
9/17	12	15
9/18	18	19
9/19	22	26
9/20	27	28
9/21	29	30
9/22	29	30
9/23	32	32
9/24	32	33
9/25	32	>33
9/26	33	>33
9/27	33	>34
9/28	34	>34
9/29	34	>34
9/30	35	>35

Preliminary Data – ECloud Energy Spectrum

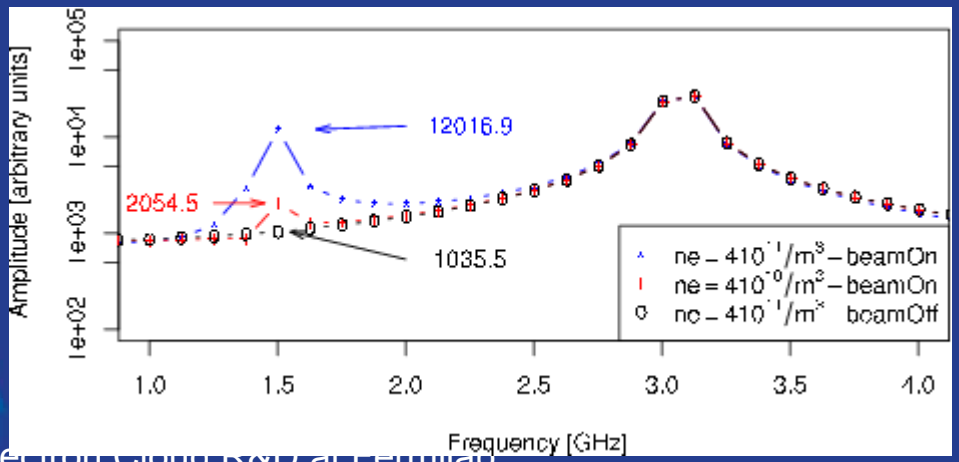
- Energy spectra created by collecting many individual pulses and differentiating
  - For now, sample size is small
- At the mercy of pulse-to-pulse variation
  - Intensity variation
  - Bunch length variation
- Initial data appears consistent with POSINST simulation
  - Bulk of electrons around 40 eV for 6e10 per bunch



Synergia Simulation

Paul Lebrun

- Have a working electron code simulation
  - Concentrating on simulating microwave measurements
- Linear approximations (Sonnad and others) verified in low-intensity regime
- Larger (more realistic) intensities and microwave amplitudes have more complicated effects
  - Paul feels strongly that AM may be contaminating PM signals (ruins normalization)
  - Looking for resonance effects (ECR and lower frequencies)



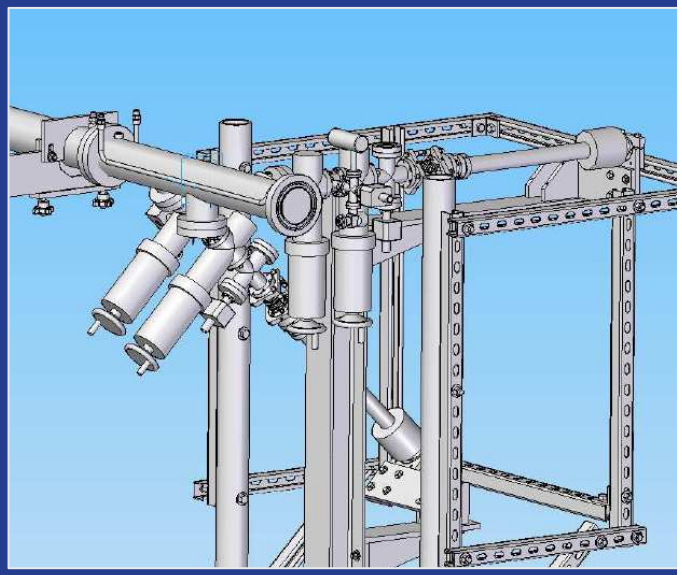
ORBIT Simulations

Leonid Vorobiev

- Adopting ORBIT simulations to MI case
  - Multibunch is crucial feature in MI beam – not working well with ORBIT model
  - Electron cloud module already rewritten for shorter bunches, but need more for multiple bunches and beam feedback
- Considering integrating other codes

Future Plans

- Chief experiment is comparing the conditioning histories for TiN and SS pipes
  - Pushing maximal intensity is also crucial
- Extrapolation to PrX intensity requires a number of hooks
  - Plan to install ECLOUD1 (SLAC) when Cornell is finished with it
  - Perhaps ECLOUD3 as well
- Simulation goal is a full ECloud simulation that can also simulate multiple-bunch instabilities



Summary

- Proton upgrades at Fermilab are our chief focus
- Major upgrade of the ECloud experimental area in the Main Injector is complete
  - Instrumentation works – collecting a lot of data
  - Initial data looks qualitatively similar to previous measurements
- TiN shows a clear suppressive effect
  - But, it needs conditioning too, and conditions more slowly
- New data will allow further cross-checks to simulation
- Planning further upgrades to installation
  - Considering the ECLOUD1 & ECLOUD3 stands from SLAC
- Need to combine simulation with experiment to be confident in solutions for Project X

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